Interactive Tangrami: Rapid Prototyping with Modular, Paper-folded Electronics

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ABSTRACT
Prototyping interactive objects with personal fabrication tools like 3D printers requires the maker to create subsequent design artifacts from scratch which produces unnecessary waste and does not allow to reuse functional components. We present *Interactive Tangrami*, paper-folded and reusable building blocks (*Tangramis*) that can contain various sensor input and visual output capabilities. We propose a digital design toolkit that lets the user plan the shape and functionality of a design piece. The software manages the communication to the physical artifact and streams the interaction data via the Open Sound protocol (OSC) to an application prototyping system (e.g. MaxMSP). The building blocks are fabricated digitally with a rapid and inexpensive ink-jet printing method. Our systems allows to prototype physical user interfaces within minutes and without knowledge of the underlying technologies. We demo its usefulness with two application examples.

Author Keywords
personal fabrication, modular fabrication, building blocks, tangibles, design tool, sensing technologies, printed electronics.

INTRODUCTION
Fabricating tangible user interfaces has been made rapid with personal fabrication tools like 3D printers, which can create interactive objects in just a few hours [5]. However, these objects are created most often out of one piece which poses a challenge in the design process. If just specific parts of a design have to be changed, it is hard for the maker to perform local changes and reuse individual segments of an object without re-creating the full object from scratch. This is particularly problematic in light of frequent design iterations, which are common in typical design processes. Requiring the maker to produce several intermediate prototypes is lengthy and results in unnecessary waste and time overflow.

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Prior work has proposed approaches for lowering the fidelty of intermediate prototypes [1] or creating light-weight paper prototypes [3]. While this has improved the process, it still requires each object to be built from scratch. Other work lets the user segment or replace certain geometric parts of model, but do not support interactive I/O components [2, 4]

We present *Interactive Tangrami*, functional paper-folded building blocks (*Tangramis*) that enable makers to prototype functional Tangible User Interfaces (TUIs) rapidly and at low cost. Each building block can be reused for other projects or can be replaced during prototyping. The Tangramis are fabricated with a rapid ink-jet printing method and can be visually customized by the user.

In the following we will present the fabrication of interactive Tangramis and a digital design toolkit that lets the maker plan and fabricate the interactive object. We show the usefulness of this system with two demonstrations.

FABRICATION OF INTERACTIVE TANGRAMIS
We will present the paper folding technique for tangramis and proceed to propose functional circuit patterns that can be embedded inside tangramis to add interactivity.

Tangrami
Tangrami folding is an established art practice and is based on simple construction blocks with pouches and plugs that can be attached into each to connect them. A description of the folding technique can be found at [6].

Embedding Interaction
We propose a set of circuit patterns for tangramis that can embed various input sensing and visual output methods. Currently, our system supports touch sensing, embedding of electrical components (e.g. LEDs) and actuated tangramis. An overview can be seen in figure 1.

For printing the conductive patterns we use an Epson ET-2550 ink-jet printer and Mitsubishi's conductive silver ink (NBSIJ). The actuated tangrami gets taped with a shape-memory polymer (polyethelene) that expands when heated above 90°C. While the underlying paper keeps its shape under higher temperatures, the tape bends the tangrami while expanding by up to 90°. We covered the heating structure of the tangrami with *Workzone PE Tape* and removed one layer of paper on the back side for less resistance while bending.

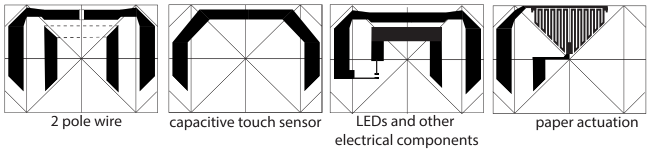

Figure 1. Ink-jet printable circuit patterns for Tangrami. 2-Pole wires transport signals through the object to capacitive touch tangramis, tangramis that can contain electrical components and tangramis that can be actuated with shape-memory polymer. Each side of a tangrami can be electrically isolated or connected.

Connecting Tangramis

Connections are formed by plugging a tangrami into another one. We found that a tangrami can be rotated up to 45° before a shortcut appears. We designed the silver traces to be large especially at the folds in order to increase their robustness and better connection between two tangramis.

We recommend for permanent installations of a tangrami object to use conductive tape between two segments. Gluing tangramis together once the artist is finished with her object is a common practice among professionals.

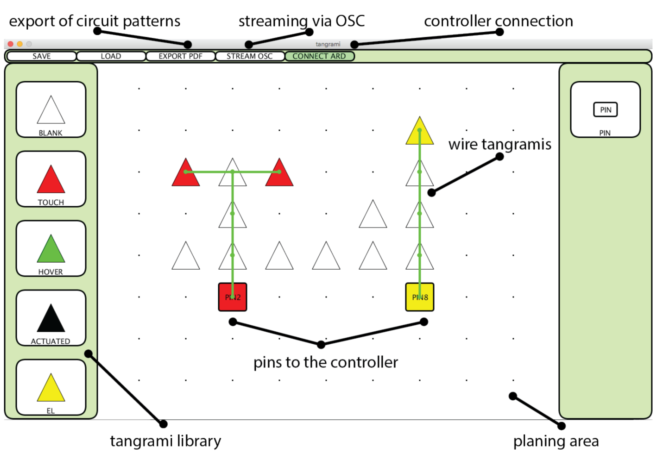

Figure 2. Digital Interface for planing a tangrami UI. The tool generates the circuit patterns and manages communication with the controller (Serial) and Application prototyping environments (e.g. MaxMSP) via OSC.

DESIGN TOOLKIT

We found through several design iterations with artists that placing and routing the functional components makes the fabrication of an interactive object difficult. Also, programming a mobile micro-controller and sending the interaction data to a computer required a trained expert. Thus, we developed a design toolkit that supports artists in creating an object with interactive tangramis and prototyping interactivity.

Figure 2 shows the design tool-kit. The artist can select from a library of functional tangramis and place them on the working area. Pin icons from a controller and a tangrami can be connected by drawing wires (green). The tool can connect and configure an Arduino Uno controller and stream the received interaction data via OSC protocol to the system. When the artist finished the planing phase, the toolkit generates all circuit patterns of the implemented tangramis and exports them as a pdf file for printing.

APPLICATION EXAMPLES

In the following we illustrate two application examples that show the usefulness of tangrami interfaces.

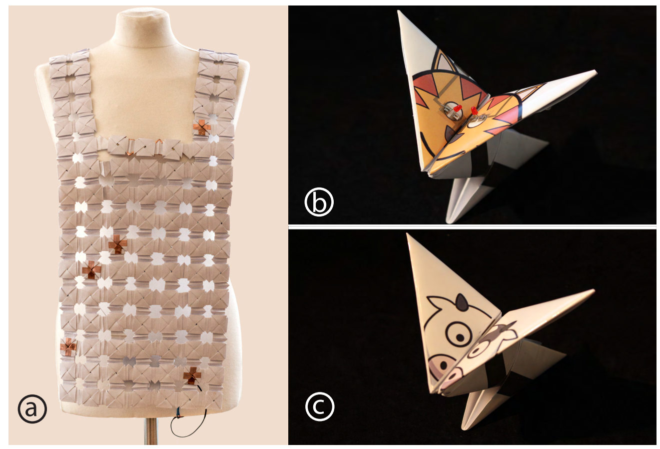

Figure 3. We implemented a tangrami dress (a) and a paper pet (b) with a replaceable head (c).

Demo 1 - Interactive Dress

We build a dress out of tangramis that contains a set of LEDs at the collar and a set of touch tangramis that can sense several body postures. Different body postures invoke an audio-visual response from the dress which helps the wearer in non-verbal communication. The piece has been exhibited at the Hager Award at the Academy of Fine Arts, Saarbrücken and the Saarland museum in Berlin, Germany.

Demo 2 - Paper Pet

We implemented a versatile paper pet out of 4 functional tangramis. The two head tangramis are customized with an individual texture. The cow head can sense being cuddled with internal touch sensors and responds with a moo-sound. The cow tangramis can be removed and replaced with a lion head that contains red LEDs as eyes. The LEDs can be turned on to leave ambient notifications in a room.

CONCLUSION

We presented *Interactive Tangrami*, modular paper-folded construction blocks that contain various input sensing and visual output capabilities. We proposed a design toolkit that supports artists in creating functional TUIs and demonstrate its usefulness with two application examples.

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